Fire, Land Cover and Climate Change: Impacts on River Flows in Semiarid Shrubland Watersheds

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ABSTRACT

This project is designed to address the following question in Mediterranean-type ecosystems (MTEs): **What is the combined effect of potential climate change and modified fire regimes on river flow characteristics that are important for water resources, ecosystem processes and functioning, and property damage?** Increased ignition sources associated with growing human populations and expected changes in climatic conditions are likely to increase fire frequencies in shrubland watersheds, typical of MTEs, over the next century. The following general hypothesis is tested for chaparral watersheds in California: **Changes in fire regime and climate will alter aggregate ecosystem conditions giving rise to modified long-term river flow characteristics.** The research hypothesis will be tested using an existing, physically based ecohydrological model (RHESSys) applied to two chaparral watersheds near Santa Barbara, California. The research project includes the following related components: 1) Time-space variations of shrub LAI during fire recovery are estimated from Landsat TM data and AVHRR data, 2) RHESSys is calibrated and evaluated using a bi-variate approach based on satellite-based estimates of LAI patterns and observed streamflow and 3) RHESSys is used to evaluate the impact of future fire and climate regimes on vegetation recovery and associated hydrologic response.

Results from this study will further our understanding of how indirect anthropogenic modifications to landcover (different fire and climate regimes) are likely to affect water resources and related ecosystems in the heavily populated semiarid MTE regions of the world. In addition, the modeling approach will contribute to our understanding of the carbon cycle in these ecosystems and ultimately will become part of an integrated modeling system for decision support. The remote sensing products (LAI) will provide a valuable time-series data set of this critical variable for other hydrologic or biogeochemical studies and MODIS validation efforts.

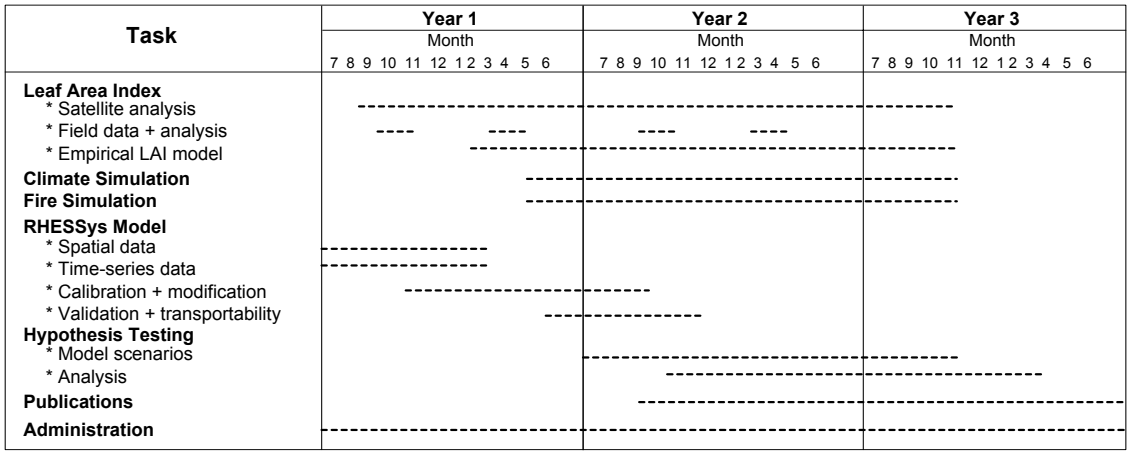
Research Fields:	Fire Ecology; Runoff, Streamflow
Geographic Area/Biome:	Semi-arid
Remote Sensing:	AVHRR; LANDSAT
Methods/scales:	Integrated Assessment; Local Scale

NASA ESE Scientific Questions and Themes

• What are the changes in land cover?
• What are the consequences of LCLUC?
Social Science: 0%
Carbon: 25%
Water: 75%

Goals

PROJECT TIME-LINE



The principal research goals of the project are to:
1) Develop empirical relationships between leaf area index (LAI) and stand age using Thematic Mapper (TM) and Advanced Very High Resolution Radiometer (AVHRR) data for two study watersheds near Santa Barbara, CA.
2) Parameterize and calibrate an ecohydrological model (RHESSys) to simulate LAI spatial patterns and river flows. Use the satellite time-space LAI patterns and observed river flows for this calibration and validation.
3) Use downscaled GCM outputs in the RHESSys model to assess the impact of climate change and altered fire frequencies on river flows.

Year two activities have continued to focus on the development of LAI – stand age relationships using an expanded time-series of TM data (23 scenes) and the adaptation of the RHESSys model for chaparral ecosystems. Downscaling of GCM predictions for watershed applications has been a new focus this year while increasing effort has been dedicated to the modeling of fire area-frequency probabilities. Field observations have continued to emphasize the relationship between modeled LAI and land-cover types.

Progress

• A chronosequence analysis of the relationship between chaparral leaf area index (LAI) derived from a time series of TM images and post-fire stand age follows trends established in field studies. LAI increases rapidly during the first 20 – 25 years after a fire and then maintains a relatively stable level for mature stands.

• The TM-derived LAI of chaparral communities shows greater inter-annual variation than expected for these evergreen communities. These variations appear to have greater association with the two year cumulative antecedent rainfall than with the antecedent rainfall of the preceding year.

• Good empirical relationships exist between point precipitation and temperature values in the research watersheds and corresponding grid values from VEMAP model simulations (Vegetation-Ecosystem Modeling and Analysis Project). Downscaling relationships are improved if the data are stratified by month/season.

• An additional deeper groundwater model was incorporated into RHESSys to account for bypass/fracture flowpaths in semi-arid environments. Extension of RHESSys calibration to the Santa Cruz watershed where daily streamflow records are available, however, shows that RHESSys consistently over-estimates recession rates.

• Development and testing of carbon cycling component of RHESSys produced estimates of a) spatial variability and b) stable post-fire recovery trajectories for LAI for Jameson watershed and two smaller watersheds (Aliso 392 ha and Lewis 173 ha) selected to emphasize the role of aspect and topography in controlling carbon cycling

• Both the RHESSys and MIKE-SHE hydrologic models exhibit a high degree of parameter equifinality (i.e., different parameter sets can yield the same model predictions). However, uncertainty bounds can be established using Monte Carlo runs and the Generalized Liklehood Uncertainty Estimation (GLUE) technique.

Over the past year we have expanded the analysis of TM and ETM data from 12 to 26 scenes covering the period 1984-2002. The fall 2002 image bands was been converted to reflectances using MODTRAN 4 (ACORN software) and all other images were radiometrically registered to this base image. We made further improvements to our radiometric registration procedure to include bootstrapping and jackknifing steps to establish confidence bounds and uncertainty measures for the correction models. NDVI and LAI images have been produced for each image date.

Since the study area is characterized by steep terrain, we examined the effect of illumination differences on the red and near infrared reflectances. The results of this study indicated that differences in the solar incidence angle had little effect on the reflectances in these two bands. We have collaborated with Dr. Xiaoliang Wu at the Australian CSIRO Mathematical and Information Sciences, Leeuwin Centre for Earth Sensing Technologies in this investigation.

Fire history data for the study area have been assembled from digital records provided by the California Department of Fire and Forestry (CDF) and in collaboration with Dr. Max Moritz at California State University Polytechnic, San Louis Obispo. These data have been used in conjunction with the TM LAI time series to construct relationships between LAI and post fire stand age. Thes LAI-stand age models replace preliminary models that we had developed using the initial 12 scene data set. A routine has been developed to derive a random distribution of fire sizes and locations for use in the hydrologic simulations.

Daily precipitation and temperature were regressed on corresponding values predicted from four GCM cells (VEMAP) that surrounded the study area. We have identified the most suitable cells for empirical downscaling and established appropriate stratification criteria (monthly/seasonal) to produce the best prediction equations. These relationships will be used to downscale the VEMAP predictions of precipitation and temperature time-series under different climate scenarios.

Comparison between MIKE-SHE and RHESSys in the Jameson watershed as well as the expansion of calibration to Santa Cruz watershed, where daily streamflow records are available, illustrated the potential for the hydrograph response to be dominated by deeper groundwater flowpaths in this semi-arid region. RHESSys results also suggests that this partitioning of flowpath has important implications for modeling feedbacks between land cover conditions and hydrologic response. To reflect this in the model, RHESSys was extended to incorporate a hillslope scale, linear groundwater model coupled to the existing rooting zone, shallow subsurface model. The coupled model produced a better correspondence between monthly observed and modeled streamflow. Daily streamflow response for the Santa Cruz, however, remains inadequate (NS < 0.4) and will be subject of further investigation in Year 3.

Continued literature review on the dynamics of chaparral vegetation led to the further refinement of BIOME_BGC parameter set for chaparral (to be made available on RHESSys web site) and incorporation of a water-stress trigger on leaf drop as part of RHESSys carbon-cycling model. These adjustments allowed the model to achieve stable post-fire LAI trajectories with mean values consistent with remote sensing and literature estimates for the Jameson watershed. RHESSys estimates of spatial patterns of LAI were shown to be sensitive to uncertainty in hydrologic paramterization, and suggest that incorporation of remote sensing imagery as part of the calibration process may be necessary. Initial analysis of RHESSys predictions in LAI, however, did show that the spatial pattern of exposed rock must be input into the model and that the model tends to a) overpredict the minimum drainage area need to produce significant riparian zone increases in LAI and b) underpredict aspect differences in LAI.

New Findings: -

New Potential:
- A more rigorous and statistically sound radiometric registration procedure.

RHESSys model, adapted for semi-arid environments, and associated chaparral vegetation parameters are available for application to other sites in Mediterranean type ecosystems.

New Products
- TM-5 time series (1985 -2000) for the study region (radiometrically and geometrically registered). Time-series of NDVI and LAI images for the same period.
- Empirical models to predict stand LAI from stand age.

Next Steps

• Use spectral mixture analysis (SMA) to derive maps of rock/bare soil areas. These patches are expected to have a significant impact on the hydrologic response of hillslopes. Aerial photography will be used as reference data to test the SMA models.
• Analyze the spring TM imagery to determine differences in LAI between fall and spring.
• Complete manuscript outlining the enhanced radiometric registration procedure.
• Develop probability models to synthesize fire size-frequency time-series. This work will be conducted in collaboration with Max Moritz at CSU Polytechnic, San Louis Obispo.
• Incorporation of a non-linear deeper groundwater model in RHESSys to better capture observed recession behavior in Santa Cruz watershed.
• Application of a multi-criteria (streamflow; TM-derived LAI patterns) approach for calibration of RHESSys for Santa Cruz watershed
• Test ability of RHESSys to capture a) between hillslope (aspect differences) and b) within hillslope (riparian/upland differences) in estimated LAI and associated post-fire recovery trajectories relative to TM-imagery for the Santa Cruz and Jameson watersheds
• Application of RHESSys to estimate hydrologic and carbon cycling response to changes in climate (VEMAP scenarios) and fire frequency.

Publications

• *Tague,C., McMichael, C., Hope, A., Choate, J. (in revision) Distributed Modeling of Seasonal Streamflow and Soil Moisture in Semi-Arid Shrublands, Journal of the American Water Resources Association.*
• McMichael, C., Hope, A. and Roberts, D. (in revision), Post-fire recovery of leaf area index in California chaparral: a remote sensing-chronosequence approach, *International Journal of Remote Sensing.*

• McMichael, C. and Hope, A. (final draft), Distributed Hydrological Modelling in Semi-Arid Shrublands: MIKE SHE Model Calibration, Uncertainty and Sensitivity, *Hydrological Processes*.

• McMichael, C., Hope, A. and Loeciaga, H. (final draft), Effects of Errors in Leaf Area Index Inputs on the Predictive Uncertainty and Parameter Sensitivity of a Distributed Hydrologic Model, *Journal of the American Water Resources Association.*

Theses/Dissertations

• C. McMichael:	"Modeling the Impacts of Fire and Post-Fire Succession on Long-Term Streamflow in Chaparral watersheds" (Dissretation to be completed by September, 2003).
• M. Anaya:	"Post-Fire Recovery Pattern of Chaparral from Thematic Mapper Time-Series Data" (In Progress)
• R. Bruce:	Modelling spatial and temporal variability in LAI for semi-arid shrubland watersheds: An evaluation of RHESSys (In Progress).

- A. Ploessel: "Mapping Rock Outcrops and Bare Soil Areas in Chaparral Ecosystems Using Thematic Mapper Data and Spectral Mixture Analysis" (In Progress).
- R. Clark "A Model for Fire Area-Frquency Probability in Chaparral Ecosystems" (In Progress).